Space Technology Research Grants

Ductility of Individual Trabeculae as a Measurement of Bone Quality to Predict Risk of Fracture

Completed Technology Project (2014 - 2018)

Project Introduction

The success and safety of future human spaceflight exploration must overcome the physiological challenges of long exposure to reduced gravity environments. Research dating back to the Skylab Program, where the first studies of physiological adaptation to long-duration spaceflight were performed, noted a decrease in bone mineral density (BMD) to the lower extremities of astronauts. Since then, mitigation of fracture risk on long-duration lunar or Mars missions where astronauts may experience high loads upon entry, descent and landing (EDL) or other exploratory tasks has been of high importance. To date, research attributes fracture of bone to low levels of BMD, but recent studies have shown fracture in bone is not only a function of quantity of bone, but also quality of bone; characterized by the bone strength and microarchitecture. For example, patients with type 2 diabetes (T2D) who have high, healthy BMD levels are more susceptible to fracture than patients without T2D. This data suggests that BMD is not the only factor affecting the risk of fracture and a factor we have not investigated with respect to long-duration space flight. Fracture of bone in humans most often occurs in locations of the body where trabecular bone dominates total bone composition, such as femoral hip fractures or vertebral fractures. Trabecular bone has a porous micro-structure comprised of connecting vertical and horizontal, thin, slender, rod- or plate-like struts called trabeculae. Therefore, I want to quantify the quality of trabecular bone at this mico-structural level, by measuring the basic mechanical failure properties of the trabeculae and characterize the bone strength. It is now known that half the strength of trabecular bone comes from its ductility, or the ability of the bone to deform before fracture occurs. Therefore the goal of the research is to determine the fundamental, post-yield mechanical properties of individual trabeculae, in particular, ultimate strain. To accomplish this, I am proposing a mechanical engineering and systems integration approach to the problem that takes advantage of recent advances in computing, imaging and 3D printing technology. A testing apparatus will be constructed to perform three-point bending tests to simulate in vivo loading conditions of the trabeculae. Finite element (FE) models of specimens will be created using microCT (Computed Tomography) scans of the specimens. By matching the experimental force-deformation curve data to the model, we can calibrate the material properties needed to achieve the curve. The technique will be demonstrated with bovine bone, a non-biohazardous material before transitioning to human tissue. Once this technique has been validated as a measure of assessing bone quality, it is a powerful tool. We can use this method to test trabeculae from bed rest patients who also have reduced BMD levels, and determine the level of bone quality. With accurate mechanical properties of trabecula we can build macro-scale FE models of trabecular and whole bone, and use these to better predict fracture occurrences for astronauts depending on mission duration and expected loads, as well as information to aid in new countermeasure development. This research can help to insure the safety and success of long-duration human spaceflight exploration.

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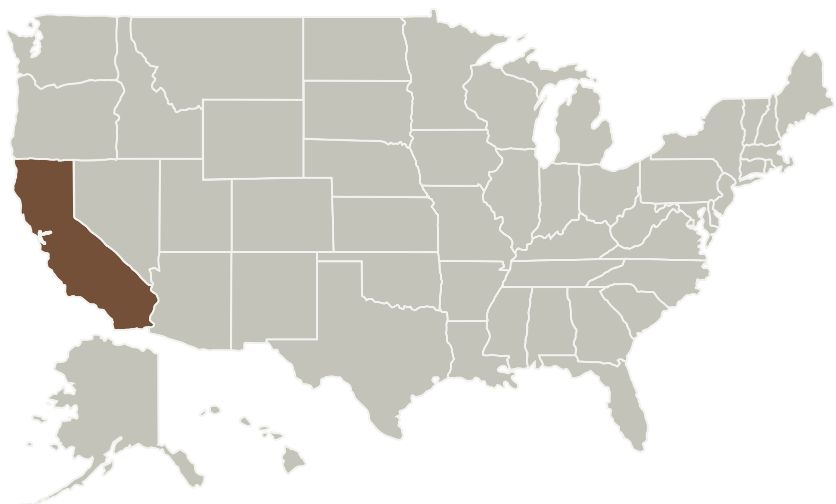
Anticipated Benefits

Mitigation of bone fracture risk on long-duration lunar or Mars missions where astronauts may experience high loads upon entry, descent and landing (EDL) or other exploratory tasks has been of high importance. This project quantifies the quality of trabecular bone at this mico-structural level, by measuring the basic mechanical failure properties of the trabeculae and characterize the bone strength.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
University of California-Berkeley(Berkeley)	Lead Organization	Academia	Berkeley, California

Primary U.S. Work Locations
California

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

University of California-Berkeley (Berkeley)

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

Tony Keaveny

Co-Investigator:

Megan M Pendleton

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**

1 2 3 4 5 6 7 8 9

Applied Research | Development | Demo & Test

Technology Areas

Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  └ TX06.3 Human Health and Performance
    └ TX06.3.6 Long Duration Health

Target Destinations

The Moon, Mars, Earth